Flat Refrigerating Unit with Countercurrent Cooling

The invention relates to a flat refrigerating unit for use as a heat exchanger for cooling air from (for example) a device cabinet, a server cabinet or a circuit cabinet, in which heat-generating equipment is installed, the heat of which is to be removed from the essentially closed housing array, in order to prevent the internal temperature of these cabinet arrays from exceeding a predetermined maximum value.

Heat exchangers as such, in the sense of a countercurrent principle in which refrigerating air flows in one direction and, in separate flow chambers, the air to be cooled flows in the opposite direction, are already known in the art. See, for example **DE-A 30 44 135** (Siemens), which describes a heat exchanger with flow channels, the cross-sections of which are oriented essentially perpendicular to the flat side of the heat exchanger and extend longitudinally; also see, [in DE-A 30 44 135,] Figure 2 and, regarding the countercurrent principle, column 6, lines 10 to 20. To charge the refrigerating chambers oriented in this manner with the air to be cooled, radial fans or tangential fans are used, which are installed in triangular storage chambers at the ends of the heat exchanger, so as to axially draw in the air and radially force it into the storage chambers (at the inlet for the air to be cooled). The same also applies at the inlet for the refrigerating air located at the opposite end. The purpose of the described solution of the prior art is to distribute the flowing air virtually uniformly across all flow channels, while maximally utilizing the housing volume for the heat exchanger.

An exchanger array that does not employ the countercurrent principle is described in **DE-A 198 04 904** (Rittal), for example, where specific locations in the interior space that are subject to elevated heat discharge can be separately cooled with tubes, wherein these cooling tubes can be easily adjusted to conform to various configurations of the interior space (see, [in DE-A 198 04 904,] the sole figure, as well as column 1, lines 54 to 58). A double-walled element on the cabinet (back) side allows heat exchange, although a countercurrent principle is not employed.

The **aim of the invention** is to further increase the performance capacity of a heat exchanger, wherein the lost heat is to be removed from the cabinet or, if applicable, a device of the same size, so that a slight increase in the internal temperature per discharged watt of power loss arises (°K per watt or W/°K).

The aim is achieved with a flat refrigerating unit using the countercurrent principle, according to at least one of the independent claims 1 to 6 or 20. Preferably, the inventions described therein can also be combined (claim 7), specifically at least two of the solutions described therein.

The air in the internal circuit and in the external circuit is conducted precisely in a countercurrent, achieving maximum effectiveness. Instead of radial fans, axial fans are used; their performance capacity is significantly higher (claim 8) and, furthermore, they present fewer diversions for the movement of the (flowing) air. The axially drawn-in air is also discharged axially and forced into the countercurrent heat exchanger in the inlet area, while the same type of axial fan—spaced at a distance from the inlet area—can also be arranged at the outlet area. Said axial fan then extracts refrigerated air from the heat exchanger and returns it to the circuit cabinet, server cabinet or device cabinet, or into a single large device (claim 16, 17). The increase in heat exchange is favorably influenced by a difference in the performance capacity, the set rotation speed or the size of the two fans producing the airflow to be cooled. The fan at the inlet area should be operated or capable of being operated at a higher rotation speed than that in the outlet area. With regard to the refrigerating air, which is also provided by two axial fans operating in accordance with the countercurrent principle, it is advantageous if these two fans, one at the inlet area of the refrigerating air and one at the outlet area of the refrigerating air (the exhaust air), possess essentially the same performance capacity, rotation speed or performance setting. Despite the fact that the maximum possible volume of refrigerating air is provided, the increased introduction of the air to be cooled results in an increase in the dwell time of the air to be cooled and—based on the current level of knowledge—also increases turbulence within the flow chambers, which results in improved heat exchange with the counterflowing refrigerating air.

The flow path of the refrigerating air is virtually straight-lined (claim 1). Between the outlet of the first fan and the second fan, the path of the refrigerating air progresses practically in a straight line through the chambers, interrupted only by the inlet area and the outlet area of the air to be cooled, which does not enter into contact with the refrigerating air, but instead is conducted through separate chambers using the countercurrent principle.

Instead of one fan, several fans can also be connected in parallel, depending on the formation, form and size of the flat refrigerating unit.

The U-shaped formation of the flow path of the air to be cooled has proven advantageous in that this air is subject to as few diversions as possible during its flow path (claim 2), wherein the axial fans contribute to this effect. Beginning at an inlet area, especially in the cylindrical design, air is forced into a first storage chamber, which is overpressured as a result of the first fan. From this storage chamber, the air is distributed across a plurality of parallel flat chambers, which extend flatly in parallel to the flat side of the heat exchanger. At the outlet area, which is oriented at a significant distance from the inlet area, oriented primarily perpendicular to the flat side of the heat exchanger, the cooled air from the individual, parallel and spaced flat chambers re-accumulates in an essentially cylindrical collection space, from which it is returned, as cooled air, into the area in which the heat arises. An additional axial fan (referred to in the claims as fourth fan), which extracts the air from the collection space, but preferably with a lower output that that of the first fan, which introduces the air into the first storage space, can be oriented at this point.

With this type of design, it is possible to fully utilize the available installed length and therefore the surface area of the sheet metal housing used for heat exchange, also eliminating the need to clear or create space for a fan in the sheet metal housing itself. In addition, the location and installed height of the flat flow channels results in a turbulent flow, which preferably provides heightened exchanger performance in panels with uneven surfaces (claim 11).

The flow chambers, referred to as flat chambers, for the air to be cooled as well as for the refrigerating air, preferably have only a slight height along their width and length (claim 5). Width and height, in this context, refers to the fact that these two dimensions describe a plane in parallel to the flat side of the heat exchanger, whereas the height is defined in the direction of the thickness, that is, perpendicular to the flat extension of the flat refrigerating unit.

In addition, the exchanger performance is increased by the fact that countercurrent exchange does not only occur after the inlet and up to the outlet for the air to be cooled,

but also downstream from the outlet (claim 4) and upstream from the inlet (claim 3).

The flat flow chambers for refrigerating air and air to be cooled, which are alternately arranged in the countercurrent principle, also extend between the outflow end of the heat exchanger and the inlet area, as well as between the inflow end for the refrigerating air and the outlet area for the air to be cooled, which at this point is already referred as "cooled air."

With regard to terminology, it should be noted that the "air to be cooled" refers to the air that is turned over as consumed air within the cabinet system and is thereby cooled. It has the lowest possible temperature upon exiting and is described here as cooled air, but also—in describing the cycle—as air to be cooled during the course of its overall path. The useful air, with which the heat exchanger is cooled, referred to as refrigerating air, and is called exhaust air in the outlet area, that is, where it has its maximum temperature. Nevertheless, the refrigerating air is still referred to as such during its entire flow path in the exchanger, so as to maintain the most uniform terminology possible for the invention being described.

It should also be noted that when describing a flat refrigerating unit, the function and mode of the unit's operation is often described by using the airflows and the flowing air, although this should not be understood to be so restrictive as to refer only to current operation. Instead, current operation is covered by a process claim (claim 20), which explains that the inlet area and the outlet area for the air to be cooled are not the ends of the respective heat exchanger, but rather that cooling areas in the countercurrent principle are also located between these areas and the respective front end (beginning). This is described in such a way that refrigerating air cooling past the inlet area is still capable of flowing [and], alternatively or cumulatively, fresh air still cooling behind the outlet area for the cooled air can also be used in the countercurrent heat exchange principle.

When the refrigerating air is still flowing past the inlet area for the air to be cooled and the cooling air is already flowing **in front of** the outlet area (claim 21), this is provided in the respective inlet and outlet areas (for the air to be cooled) in such a way that it occurs along a width which is not less than the width, especially the diameter, of the inflow area or the outflow area itself (claim 21).

The distance between the metallic sheets separating the chambers (claim 23, claim 6) can be deduced from the height of the flowing air layers (claim 23). The latter chambers are sealed with dividers in the form of fins, creating separate, alternating chamber systems for the cooling air and for the air to be cooled (claims 6, 19, 18, 9, 10).

An additional increase in cooling performance or heat loss performance in the heat exchanger can be achieved with blocking elements (claim 12), which block a direct (short) flow path for the air to be cooled and divert this air from the shortest flow path into a longer flow path to encourage a turbulence or a turbulent flow. These blocking elements can be designed as curved elements, which are especially adjustable (claim 13, 14). These are oriented in the inlet area and in the outlet area, preferably opposite one another.

With as few right-angled diversions as possible, the invention ensures countercurrent flow and utilizes the available chambers as completely and uniformly as possible. Technical experiments were conducted to test the premise that a heat exchanger achieved more than double the cooling performance of currently available air heat exchangers in the countercurrent principle. Values greater than 400 W/°K were achieved with a heat exchanger with the external dimensions of 100 cm length, 40 cm width and 18 cm height (thickness).

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The invention is described in detail in the following on the basis of **exemplary** embodiments.

Figure 1 is a view of the flat side 51 of a heat exchanger with an inflow opening 13 and outflow opening 23 to the air to be cooled and/or the cooled air. Two traverses A and B are indicated.

Figure 2 is a cross-section along plane A of Figure 1.

Figure 3 is a cross-section along plane B of Figure 1.

Figure 4 illustrates an advantageous augmentation of the arrangement of Figure 1, the cross-sections of Figures 2 and 3 also applying correspondingly to this arrangement, with the corresponding segments 18, 29, which are not drawn into Figures 2 and 3.

Figure 1 illustrates a top view of the flat side 51 of the flat refrigerating unit. Provided in the flat side 51 are two recesses 13 and 23, which are oriented primarily along a central plane A, but are significantly spaced from one another in longitudinal direction I of the flat refrigerating unit. They are also arranged at a distance I_{23}, I_{13} between their respective centers and the upper and lower front end of the flat refrigerating unit in the front flat side 51. Grooves 23 and 13 are circular and, in the cross-section along plane A, cylindrical spaces extent at depth h of the refrigerating unit (see **Figure 2**). The width of the refrigerating unit extends perpendicular to the length and is referred to with b in Figure 1. The refrigerating body is significantly longer than it is wide. The depth (thickness) in direction h is, in turn, significantly less than the width. However, the depth can also be significantly increased if a plurality of the sheet metal walls 50a, 50b, 50c to be described later are used to define the flow chambers k1, k2, k3, etc.

Assuming a circular opening 13 for entry of the air to be cooled and a circular opening 23 for discharge of the cooled warm air and/or the cold air returning into the circuit cabinet, the storage space 11 behind the inlet 13 and the collection space 21 behind the outlet 23 are both cylindrical. These areas are also referred to as inlet area and outlet area. Arranged in front of the inlet area 13 is a first axial fan 10, which forces the warm air SL (suction air) to be cooled into an airflow in the first storage chamber 11. A second fan 20 can be arranged in the outlet opening 23, in order to draw

cooled air from the collection chamber 21 and return it into the cycle as compressed air DL.

Flat side 51 in Figure 1 is mounted as a wall or to a wall of a cabinet housing, such as a device cabinet, a server cabinet or a circuit cabinet, with corresponding openings, such as a door, a side wall or the rear wall. As a result, the openings 13, 23 have access to the interior of the cabinet, which can also be closed and are usually closed. As a result of turnover of the warm air volume in the cabinet through the heat exchanger, which, for its part, as a result of refrigerating air KL in the countercurrent principle, causes cooling of the circulated cabinet air, said refrigerating air then exits as exhaust air AL at the opposite end.

This flow of the refrigerating air KL, L4, AL occurs along the flow chambers, which will be described later in cross-section.

The airflow for cooling is illustrated schematically by the arrows in Figure 1. It is supported by two inlet fans 30, 31 shown in the drawing, which are arranged adjacent to one another and are electrically connected in parallel. Also arranged adjacent to one another and also electrically connected in parallel are two outlet fans 40, 41, all fans being based on the principle of axial airflow, that is, with an axis of rotation and an internal carrier, on which the radial blades that compress and move the air are arranged. Air enters axially and exits axially, the end of the inlet fans 30, 31 defining the beginning of the heat exchanger and the beginning of the outlet fans 40, 41 defining the end of the heat exchanger.

Because the openings 13, 23 are arranged at a distance from the lower end and the upper end, they are at a distance b1, b2 and b3, b4, respectively, from the lateral longitudal sides (narrow sides) of the heat exchanger. As a result, the inflow area 13 and the outflow area 23 are placed in the heat exchanger in such a way that—viewed in the direction of flow of the air to be cooled KL—an exchanger surface is also found upstream from the outlet area 23 and downstream from the inlet area 13. Exchanger surfaces are also provided next to the outlet area and next to the inlet area, so that it is possible to rinse the collection chamber and/or storage chamber 21, 11, cylindrically shaped in this case.

The flow widths b1, b2 as well as b3, b4 should, taken together in each case, at least fall within the range of the diameter d13 and d23 of the opening 13, 23,

but, preferably, can also be designed to be larger. The number of axial fans 30, 31, 40, 41 on the inlet face side and the outlet face side of the flat refrigerating unit depends on these dimensions. Several axial fans can be connected in parallel, as can fewer.

The heat exchanger is closed on the longitudinal face sides, which is achieved with a stack of fins 52 that completely seal the individual chambers between the back rear wall 50 and the front wall 51 visible in Figure 1. Sealing fins 32a, 32b, 32c, etc., are also provided in the upper face area, but they only seal every other chamber to the exterior, just as, in the lower face area near the fans 40, 41, only every other chamber is sealed to the exterior with fins 42a, 42b, 42c, in short, 42. The chambers that are sealed with fins 32 or 42 on the face side are the same chambers, and/or the fins 32, 42 are located at the same plane level relative to the flat side 51.

This orientation of the flow chambers is illustrated by the two sections along planes A and B, the section along plane A illustrating the storage chamber and the collection chamber 11, 21, where the sectional view in Figure 3 along plane B illustrates the entire flow path, which shows that the fins 32 and the fins 42, respectively, both seal the same chamber on its face (toward the exterior). These flat flow chambers k1, k3, k5, k7 are the same flow chambers (with uneven indices) that accept the upward-flowing warm air to be cooled L3. It originates in the collection chamber 11, as a result of the fan pressure from the suction air SL to the airflow L1, and terminates in the collection chamber 21, diverted along the flow path L5 and drawn in by the axial fan 20 to form compressed air DL at the outlet of the second axial fan 20.

The flow chambers k2, k4, k6, k8, in contact with the exterior air in Figure 3, are the flow chambers that accept the cooling exterior air L4 and, in the countercurrent principle, conduct it to the airflow L3 in the other chambers with the uneven k-indices. They are not closed with fins at the face ends, but rather in the areas of inflow 13 and outflow 23 for the (heated) air to be cooled. The fins shown here, 22a, 22b, 22c (22, in short) and 12a, 12b, 12c (12, in short), tightly seal the exterior air flow spaces from the interior air. In the top view in Figure 1, these fins are visible, schematically, around the inlet 13 and around the outlet 23. Like the fins 32, 42, they provide a physical

separation between the extended, flat flow chambers, which conduct the exterior air, and those of other parallel flow chambers, which conduct the interior air.

The countercurrent principle is evident in Figures 2 and 3. Figure 1 also illustrates the stacking of the individual flat flow chambers and the flat extension of these flat flow chambers, with each flow chamber extending between the face-end longitudinal side 52, the face-end narrow sides 32, 42 and the fins 12 and 22, and around the inlet and outlet areas. The flat extension of the chambers is significantly larger, in terms of its width and length, than the height h of each of the chambers, the height of chamber k1 being indicated as h1 and the height of chamber k2 as h2 in Figure 3. The other heights of the other chambers are analogous.

All chambers have, at the same fin height, practically the same height (thickness), each of the chambers being two-dimensionally delimited by individual layers of sheet metal 50a, 50b, 50c. The sheet metal layers can also be designed to be uneven perpendicular to their extension, by means of corrugation or embossing, in order to enlarge the heat exchanger surface area between the chambers. However, they are impermeable to air flow, in order to physically separate the refrigerating air from the air to be cooled.

In an exemplary embodiment, the chamber heights are less than 10 mm, preferably less than 5 mm. In the example, the fins 12, 42 as well as 22, 32 are cemented to sheet metal panels 50a, 50b, 50c to achieve an airtight seal. The stacked fins 52 can also be cemented to the sheet metal in the edge zone in the face-end longitudinal area, and can also be reinforced with a screw connection.

In an embodiment of the heat exchanger, as shown in **Figure 4**, a curved cover plate 18, 28 acts as a supplementary flow-blocking element at the lower end of the outlet opening 23 and at the upper end of the inlet opening 13. It can extend entirely into the depth of the storage space 11 and into the depth of the collection space 21. Otherwise, the heat exchanger shown in Figure 4 is designed in plane B in the same manner as described on the basis of Figures 1 to 3. A sectional view of the heat exchanger shown in Figure 4 would correspond to exactly the same sectional view as shown in Figure 3, with the same countercurrent principle and the same chamber height of the flat flow chambers. In Figure 2, a covering would occur in the area of discharge of the air to be cooled L3 from the flow chambers near the lower segments of the fins 22a, 22b

and below the upper fin segments 12a, 12b upon entry of the air flow L1 into the flow chambers, although said covering would not extend across the entire width of the flat flow chambers. In this case, the flow L1 would first be diverted into the lateral areas of segments b1, b2 at the inlet, and would then be conducted along the flat central segment of the current exchangers. The resulting additional turbulence enhances the turbulent flow effect, thereby providing stronger heat exchange activity and higher heat transfer output to the counterflowing cooling air L4.

The matching of the electric outputs of the fans, but also of their sizes or their real operated rotation speed, should preferably occur in such a way that fan 10 is operated at higher output than fan 20. The storage chamber 11 thereby receives a stronger overpressure than can be reduced by the vacuum of the collection chamber 21. This technical design or this technical operation of the heat exchanger also provide for stronger turbulence and an increase in the turbulence effect in the flat flow chambers. Various methods for changing the output of the lower fans are possible as alternatives. Various fan types (based on installation size) can be used as fans 10 or 20. The same fans can be used, but operated differently, and different fans can be used that are operated differently but based on the same described condition.

In contrast, the fans 30, 31 and 40, 41 should be essentially equal in power, that is, achieve the same air throughput.

The cooling effects achieved with the described arrangement could be increased by 20% to 30% if the diversion surface or guide surface, in the sense of blocking elements 18, 28, were added to the embodiment shown in Figure 1, which is already outstanding in terms of heat exchange performance. In this connection, the dwell time of the air to be cooled in the elongated flat chambers is achieved in addition to the increase in turbulence. The shortest path, that is, the short circuit for the air SL, L3, DL conducted in a U-shaped flow, is blocked and, despite the fact that the essentially U-shaped flow direction is essentially preserved, the lateral segments b3, b4, b1, b2 adjacent to the inflow opening 13 and adjacent to the outflow opening 23 are involved in heat exchange, which also applies to the front segment I_{23} and the rear segment I_{13} of the heat exchanger relative to the flow direction of the exterior refrigerating air KL, AL. Around the inlet opening

(outside the sealing fins 12) and/or around the outlet opening 23 (around the fins 22 that seal here), the external refrigerating air can exert its cooling action. During the essentially linear passage through the corresponding flat channels k2, k4, k8, the inflow and outflow areas can be flushed. This flushing can be influenced by adjusting the curved blocking elements 18, 28, which adjustment can be oriented in a circumferential direction or in an axial direction by pushing in and removing from the cylindrical collection chamber 11 and/or the cylindrical acceptance chamber 21.

The shape of the chambers 11, 21 is not limited to a cylindrical form. Instead, geometries varying within a closer range, such as ellipses and polygons, can also be selected. It is advantageous, however, when the chamber extends completely into the depth of the heat exchanger and occupies the entire height of the flat refrigerating unit.

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